EXPERIMENTAL INVESTIGATION ON FLY ASH BRICKS USING POLYPROPYLENE FIBRES

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ABSTRACT

The utilization of fly ash in brick manufacturing offers a sustainable alternative to conventional clay bricks while addressing industrial waste disposal issues. However, fly ash bricks exhibit brittle behavior and susceptibility to cracking. This study experimentally investigates the effect of polypropylene (PP) fiber reinforcement on the mechanical and durability properties of fly ash bricks. Fly ash bricks were produced with polypropylene fiber contents of 0%, 2.5%, 5%, and 7.5% by weight. Compressive strength and water absorption tests were conducted at 14 and 28 days of curing. Results indicated that the addition of polypropylene fiber significantly improves compressive strength and reduces water absorption up to an optimum fiber content of 2.5%. Beyond this level, performance declined due to poor workability and increased porosity. The study demonstrates that polypropylene fiber-reinforced fly ash bricks with optimal dosage provide a durable and eco-friendly masonry material.

Keywords: Fly ash bricks, Polypropylene fiber, Compressive strength, Water absorption, Sustainable construction

1. INTRODUCTION

1.1 General

Rapid urbanization and infrastructure development have resulted in extensive use of conventional burnt clay bricks, leading to depletion of natural clay resources and increased environmental pollution. Fly ash, a by-product from coal-based thermal power plants, poses a serious disposal problem but offers immense potential as a sustainable construction material. Fly ash bricks are eco-friendly, cost-effective, and exhibit superior durability compared to conventional bricks.

However, fly ash bricks are susceptible to micro-cracking due to shrinkage and brittle behavior. To overcome these limitations, fiber reinforcement has emerged as an effective solution. Polypropylene (PP) fiber, a synthetic polymer with high tensile strength, chemical resistance, and low density, acts as micro-reinforcement within the brick matrix. The incorporation of PP fibers enhances crack resistance, compressive strength, and durability while reducing water absorption. This experimental investigation aims to study the effect of varying polypropylene fiber content on the mechanical properties of fly ash bricks, focusing on compressive strength and water absorption, thereby contributing to sustainable and high-performance masonry construction.

The construction industry plays a crucial role in the economic development of any nation, but it is also one of the largest consumers of natural resources and contributors to environmental degradation. Conventional building materials such as burnt clay bricks require large quantities of fertile soil and energy-intensive manufacturing processes, resulting in depletion of natural resources and increased greenhouse gas emissions. In recent decades, the growing emphasis on sustainable development has encouraged researchers and engineers to explore alternative construction materials that are environmentally friendly, cost-effective, and structurally reliable.

Fly ash bricks have emerged as a promising alternative to traditional clay bricks. Fly ash, a fine particulate residue generated from coal combustion in thermal power plants, poses a serious environmental challenge due to its large-scale generation and disposal requirements. Utilization of fly ash in brick manufacturing not only addresses waste management issues but also reduces the consumption of natural clay and lowers carbon emissions associated with brick production. Fly ash bricks are known for their uniform shape, smooth finish, high compressive strength, and reduced water absorption compared to conventional clay bricks. Despite these advantages, fly ash bricks exhibit certain limitations, particularly their brittle nature and susceptibility to micro-cracking during drying and curing. These cracks can adversely affect the mechanical performance and long-term durability of masonry structures. To overcome these shortcomings, the incorporation of fiber reinforcement into fly ash bricks has gained significant attention in recent years.

1.2 Polypropylene Fiber and Its Characteristics

Polypropylene (PP) fiber is a synthetic thermoplastic polymer fiber widely used as micro-reinforcement in cement-based composites. It is characterized by high tensile strength, low density, chemical inertness, and excellent resistance to acids, alkalis, and moisture. Due to its hydrophobic nature, polypropylene fiber does not absorb water, making it particularly suitable for construction materials exposed to moisture.

Key properties of polypropylene fiber include:

- Low specific gravity
- High tensile strength and flexibility
- Resistance to chemical and biological degradation
- Non-corrosive and non-magnetic behavior
- Ease of mixing and uniform dispersion

When incorporated into fly ash bricks, polypropylene fibers act as secondary reinforcement, controlling plastic shrinkage and early-age cracking. They improve the bonding between particles within the brick matrix and enhance load transfer mechanisms under compressive and tensile stresses. However, excessive fiber content may lead to problems such as poor workability, fiber agglomeration, increased porosity, and difficulty in compaction. Therefore, determining the optimum fiber dosage is essential to maximize benefits without compromising brick quality.

1.3 Need for the Present Study

Although several studies have explored the use of polypropylene fibers in cement concrete and mortar, limited research has focused specifically on fly ash bricks reinforced with polypropylene fibers, particularly with respect to optimum fiber content and its influence on compressive strength and water absorption. Most existing studies indicate that fiber addition improves strength up to a certain limit, beyond which performance deteriorates due to poor fiber dispersion. Additionally, water absorption behavior—an important indicator of durability—needs to be carefully evaluated for fiber-reinforced fly ash bricks.

There is a clear need for systematic experimental investigation to:

- Evaluate the effect of varying polypropylene fiber content on fly ash brick performance
- Identify the optimum fiber dosage for maximum strength and durability
- Assess water absorption characteristics and durability implications
- Promote sustainable construction by utilizing industrial waste materials

The present study aims to address these aspects through controlled laboratory experimentation and analysis.

1.4 Objectives of the Study

The primary objectives of this experimental investigation are:

1. To study the feasibility of incorporating polypropylene fiber in fly ash bricks.
2. To evaluate the effect of different percentages of polypropylene fiber on the compressive strength of fly ash bricks.
3. To assess the water absorption characteristics of polypropylene fiber-reinforced fly ash bricks.
4. To determine the optimum fiber content that yields maximum strength and minimum water absorption.
5. To compare the performance of fiber-reinforced fly ash bricks with conventional fly ash bricks.
6. To contribute toward sustainable and eco-friendly construction practices.

2. LITERATURE REVIEW

Several researchers have investigated fiber-reinforced fly ash bricks to improve their structural performance. Studies indicate that polypropylene fibers effectively control shrinkage cracks and enhance tensile behavior. Ahuja and Kumar (2018) reported improved compressive strength with low fiber dosage, while Banerjee and Patel (2017) highlighted the sustainability benefits of PP fiber incorporation. Research by Mishra and Gupta (2021) demonstrated that excessive fiber content may lead to fiber agglomeration, adversely affecting strength. Nath and Verma (2018) observed reduced water absorption due to improved pore structure with optimal fiber addition. Thermal and durability studies by Bhardwaj and Sharma (2020) confirmed enhanced resistance to environmental stresses.

The study by M. T. Mujeeb et al. (2025), “Experimental investigation of fly ash brick using polypropylene fiber” demonstrates that the inclusion of polypropylene (PP) fibers significantly enhances compressive strength and crack resistance of fly ash bricks due to fiber bridging, though excessive fiber content leads to workability issues. Similarly, C. Wungsumpow et al. (2025), “Utilizing fly ash from municipal solid waste and polypropylene fiber to improve the flexural properties of compacted cement sand” highlights improved flexural strength and ductility with PP fibers, while emphasizing optimal dosage to avoid poor dispersion.

Z. Yuan et al. (2025), “Study on the improvement effect of polypropylene fiber on the mechanical properties and freeze–thaw degradation performance of high fly ash content alkali-activated concrete” reports enhanced strength and durability, particularly under freeze–thaw conditions, confirming the role of fibers in reducing degradation. In contrast, M. R. Maaze et al. (2025), “A holistic approach and framework to optimize fly ash cement bricks incorporating sustainability assessment” focuses on optimizing fly ash brick composition using sustainability metrics such as CO_2 reduction and energy efficiency. The review by S. A. Ahmad et al. (2024), “An overview of the impact of fly ash and polypropylene fiber on the mechanical properties of foam concrete” establishes a synergistic effect between fly ash and PP fibers, improving strength and durability while maintaining sustainability. Likewise, Y. Wang et al. (2024), “Synergistic effects of polypropylene fiber and fly ash ceramsite on mechanical properties of concrete under freeze–thaw cycles” confirms improved toughness and durability under harsh environmental conditions.

Further, P. Yoosuk et al. (2023), “Properties of polypropylene fiber reinforced fly ash geopolymer mortar” demonstrates enhanced flexural strength and ductility, though with reduced workability. N. Poranek et al. (2023), “Recycle option for municipal solid waste incineration fly ash as partial cement replacement” emphasizes sustainable waste utilization, noting the need for treatment to address environmental concerns. Earlier studies such as P. Jamsawang et al. (2022), “Flexural strength characteristics of compacted cement–polypropylene fiber sand” and J. Blazy and R. Blazy (2021), “Polypropylene fiber reinforced concrete and its application in construction” confirm that PP fibers significantly improve ductility, crack resistance, and toughness of cementitious materials.Overall, the literature consistently indicates that polypropylene fibers enhance mechanical performance, durability, and crack resistance of fly ash-based materials, with optimal dosage being critical to balance strength and workability while ensuring sustainability.

Across the surveyed literature the major convergent points are:

1. **Sustainability rationale**: Fly ash reuse in bricks reduces environmental burden and fossil fuel use associated with fired bricks.
2. **Fibre benefits**: PP fibres at low dosages enhance micro-crack control, impart post-crack toughness and can slightly increase compressive strength.
3. **Optimal dosage**: Most studies report an optimum fibre content around 1–3% (by weight) — above this, compaction and dispersion issues typically negate benefits.
4. **Manufacturing controls**: Process parameters (compaction energy, curing regime) substantially affect final properties and must be standardized.
5. **Durability**: Preliminary evidence indicates improved durability at optimal fibre content, but long-term field data are scarce.
6. **Variability in reporting**: Wide variability in mix proportions, fibre definitions, and test protocols complicates meta-analysis.

These trends support the methodological choices and findings of the attached study which observed optimum performance at 2.5% PP content for compressive strength and lower water absorption

Identified Research Gaps and Opportunities

1. **Long-term field performance**: There is limited longitudinal monitoring of fibre-reinforced FABs in real climatic exposure. Multi-year studies would validate laboratory results.
2. **Wall and structural performance**: Brick-level improvements should be linked to masonry unit and wall-level performance (bond strength, masonry shear, thermal bridging).
3. **Scale-up and industrial protocols**: Studies focusing on industrial-scale production, including mixing machinery adaptations and quality control procedures for fibre dispersion, are needed.
4. **Lifecycle and economic assessment**: Comprehensive life cycle analysis (LCA) and cost-benefit studies to quantify environmental advantages and market viability.
5. **Standardization and codes**: Development of specifications for fibre content, test methods for fibre-reinforced masonry, and acceptance criteria.
6. **Hybrid reinforcement strategies**: Combining PP fibres with other additives (nano-silica, pozzolans, or polymeric dispersants) to improve dispersion and matrix bonding.
7. **Alternate fibre geometries and surface treatments**: Studying fibrillated vs monofilament fibres, coated fibres, and surface treatments to enhance bonding and reduce balling.

3. MATERIALS AND METHODS

3.1 Materials

Cement: Ordinary Portland Cement (OPC) of 53 grade was used as a binding material. Cement provides early strength and facilitates bonding between fly ash particles and sand. The cement used was fresh and conforming to IS 12269.

Sand: Crushed sand was used as a filler material in the fly ash brick mix. The sand was clean, well-graded, and free from clay, silt, and organic impurities. The particle size distribution of sand was maintained within permissible limits for masonry applications.

Polypropylene Fiber: Polypropylene (PP) fiber is a synthetic thermoplastic polymer fiber used as micro-reinforcement in this study.

Properties of Polypropylene Fiber:

- Low density
- High tensile strength
- Chemically inert
- Non-corrosive
- Hydrophobic nature

Role of Polypropylene Fiber:

- Controls plastic shrinkage cracks
- Improves tensile resistance
- Enhances post-cracking behavior
- Reduces water absorption by limiting crack propagation

The fibers were uniformly dispersed during mixing to avoid agglomeration.

Fig. 3.1 Polypropylene Fiber

Water

Potable water free from impurities was used for mixing and curing. Water plays a critical role in hydration of cement and pozzolanic reactions of fly ash.

3.2 Mix Proportions

The mix proportions were designed to study the influence of varying polypropylene fiber content on fly ash brick properties.

Mix Combinations and Designation

Four different mixes were prepared by varying polypropylene fiber content.

Table 3.1 Mix Designation

Mix ID	**Fiber Content (% by weight)**	**Description**
M0	0%	Control mix
M1	2.5%	Low fiber content
M2	5%	Medium fiber content
M3	7.5%	High fiber content

All other constituents were kept constant for all mixes.

3.3 Manufacturing and Curing

Dry materials were thoroughly mixed, followed by gradual addition of polypropylene fibers to ensure uniform dispersion. Water was then added to obtain a cohesive mix. Bricks were moulded using a compaction machine, demoulded immediately, and cured using water curing for periods of 14 and 28 days.

Fig. 3.2 Addition of polypropylene fiber **Fig. 3.3 Mixing of Mortar**

Fig. 3.4 Preparation of FABs **Fig. 3.5 Drying of FABs**

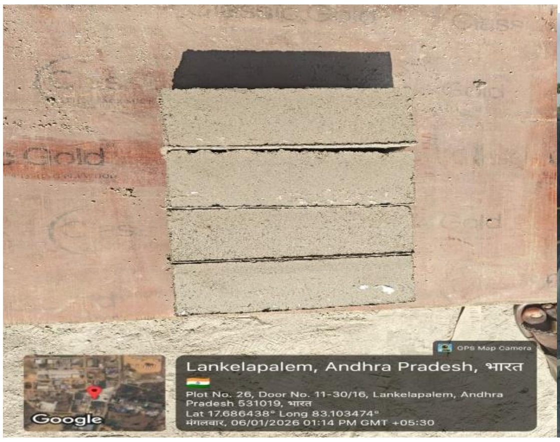

Fig. 3.6 Dried FABs **Fig. 3.7 Water curing of FABs**

Standard size fly ash bricks were produced.

Table 3.2 Specimen Details

Parameter	Value
Brick size	Standard fly ash brick
Number per mix	Minimum 6
Total specimens	24

3.4 Testing Procedures

Compressive strength was determined using a compression testing machine by applying load until failure.

Water absorption was measured by oven-drying the specimens, immersing them in water for 24 hours, and calculating the percentage increase in weight.

4. RESULTS AND DISCUSSION

The performance of the bricks was evaluated in terms of compressive strength and water absorption at curing ages of 14 days and 28 days. The results are presented in tabular and graphical form, followed by a detailed analytical discussion aimed at understanding the influence of polypropylene fiber content on mechanical strength, durability, and failure behavior. The discussion emphasizes comparison between control bricks and fiber-reinforced bricks, identification of optimum fiber dosage, and interpretation of observed trends based on material behavior and microstructural considerations.

4.1 Compressive Strength

Table 4.1 Compressive Strength Results (14 Days)

Mix ID	Fiber Content (%)	Compressive Strength (N/mm²)
M0	0	5.86
M1	2.5	**6.28**
M2	5.0	5.98
M3	7.5	5.84

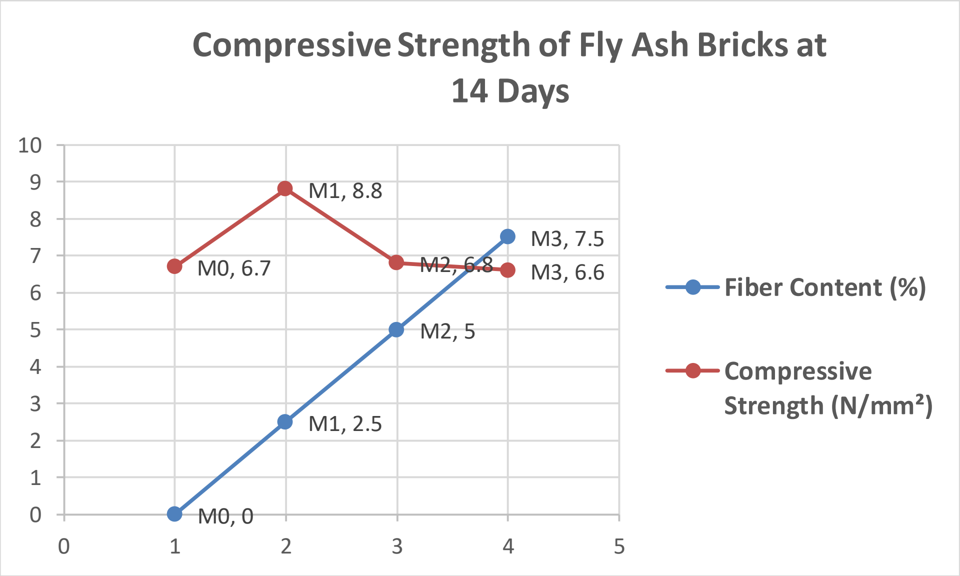

Figure 4.1: Graph showing variation of compressive strength at 14 days with fiber content.

Discussion

From Table 4.1 and Figure 4.1, it is observed that the compressive strength of fly ash bricks increased with the addition of polypropylene fiber up to 2.5% by weight. The maximum compressive strength at 14 days was recorded for mix M1 (2.5% fiber), showing an increase of approximately **7.2%** compared to the control mix. The improvement in strength at low fiber dosage can be attributed to:

- Effective crack bridging by polypropylene fibers
- Reduction in early-age shrinkage cracks
- Improved stress distribution within the brick matrix

However, further increase in fiber content beyond 2.5% resulted in a reduction in compressive strength. This reduction is likely due to:

- Fiber agglomeration
- Increase in void content
- Reduced workability and compaction efficiency

Table 4.2 Compressive Strength Results (28 Days)

Mix ID	Fiber Content (%)	Compressive Strength (N/mm²)
M0	0	6.70
M1	2.5	**8.80**
M2	5.0	6.80
M3	7.5	6.60

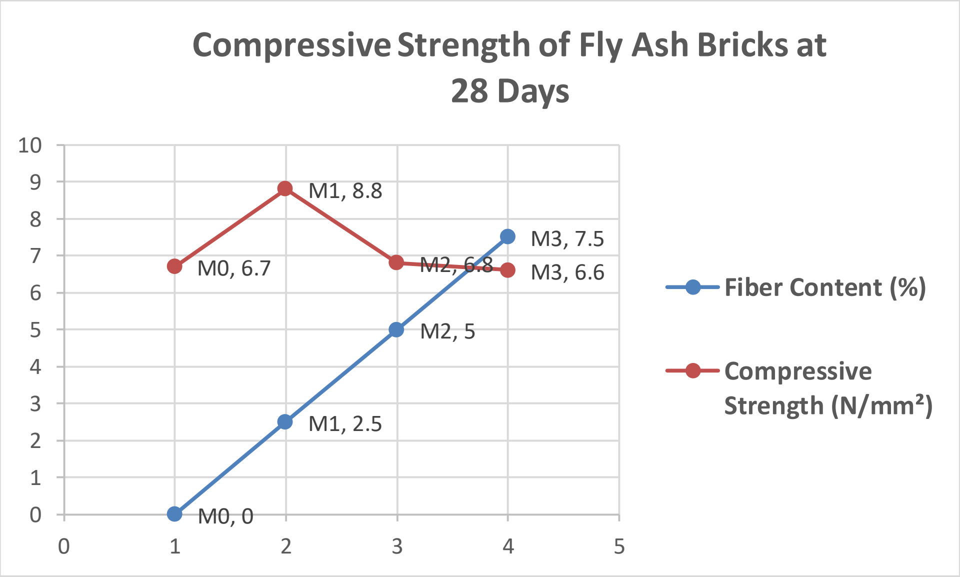

Figure 4.2: Graph showing variation of compressive strength at 28 days with fiber content.

Discussion

At 28 days, a significant increase in compressive strength was observed for fiber-reinforced bricks. Mix M1 (2.5% fiber) exhibited the highest compressive strength of **8.8 N/mm²**, representing an improvement of approximately **31%** compared to the control mix. This substantial gain in strength at 28 days is attributed to:

- Continued hydration of cement
- Pozzolanic reaction of fly ash
- Improved fiber–matrix bonding over time

For mixes M2 and M3, the compressive strength values were comparable to or slightly lower than the control mix, indicating that excessive fiber content adversely affects strength development

The compressive strength results showed an increase with the addition of polypropylene fiber up to 2.5% by weight. At 14 days, the strength increased from 5.86 N/mm² (control) to 6.28 N/mm², while at 28 days it increased from 6.70 N/mm² to 8.80 N/mm². This improvement is attributed to effective crack bridging and enhanced fiber–matrix interaction. Beyond 2.5% fiber content, compressive strength decreased due to fiber agglomeration, reduced workability, and increased void content, which adversely affected compaction and density.

4.2 Effect of Curing Age on Compressive Strength

Table 4.3 Strength Gain with Curing Age

Mix ID	14 Days (N/mm²)	28 Days (N/mm²)	% Increase
M0	5.86	6.70	14.3
M1	6.28	8.80	**40.1**
M2	5.98	6.80	13.7
M3	5.84	6.60	13.0

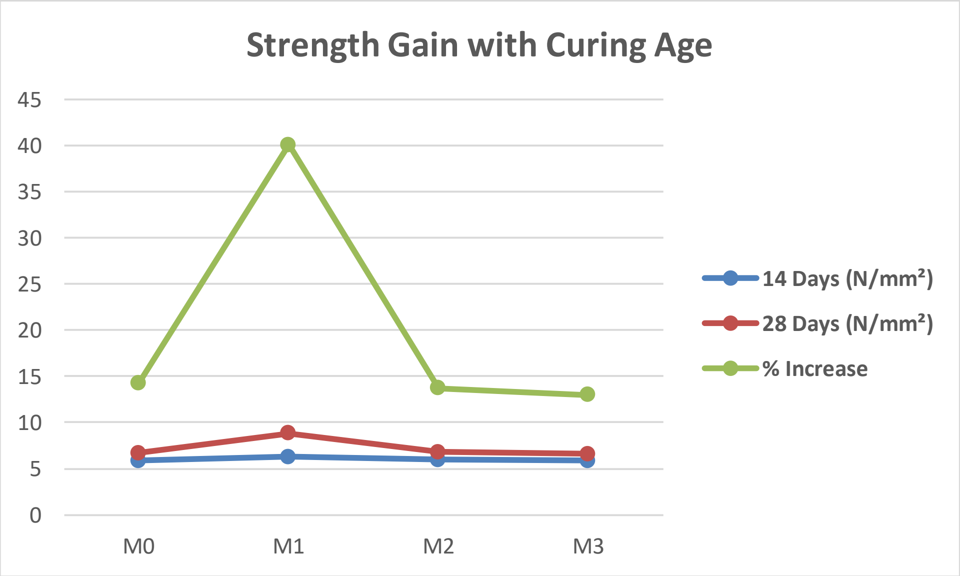

Figure 4.3: Line graph showing strength development with curing age

Discussion

The rate of strength gain was highest for the 2.5% fiber-reinforced bricks. The presence of polypropylene fibers enhanced the effectiveness of pozzolanic reactions by controlling crack formation and maintaining matrix integrity during curing. This resulted in superior long-term strength performance.

4.3 Water Absorption

Test Procedure

1. Oven-drying of bricks
2. Recording dry weight
3. Immersion in water for 24 hours
4. Recording wet weight

Water absorption decreased with fiber addition up to 2.5%, indicating improved pore structure and reduced micro-cracking. At 28 days, water absorption reduced from 6.28% (control) to 6.00% for the 2.5% fiber mix. Higher fiber contents resulted in increased water absorption due to increased porosity.

The reduction in water absorption indicates:

- Reduced micro-cracking

- Improved pore structure
- Better matrix cohesion

Higher fiber content led to increased water absorption due to increased porosity and fiber clustering.

Table 4.5 Water Absorption Results (28 Days)

Mix ID	Fiber Content (%)	Water Absorption (%)
M0	0	6.28
M1	2.5	**6.00**
M2	5.0	6.20
M3	7.5	6.25

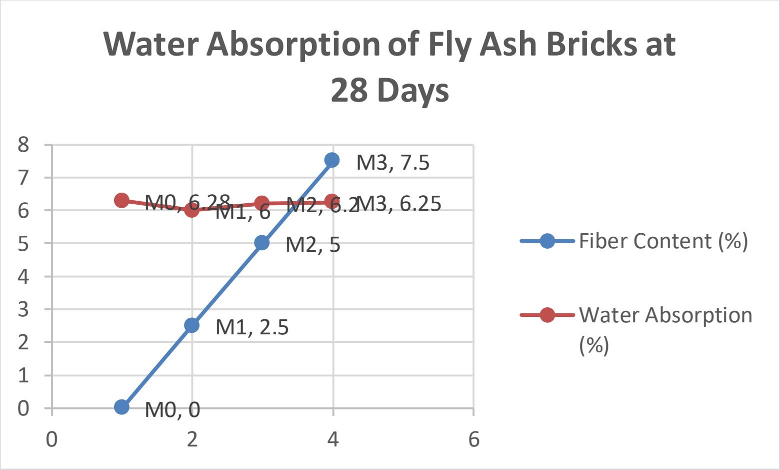

Figure 4.4: Graph showing water absorption at 28 days.

4.4 Optimum Fiber Content

Both compressive strength and water absorption results clearly indicate that **2.5% polypropylene fiber by weight** is the optimum dosage for fly ash bricks.

4.5 Effect of Excess Fiber Content

Higher fiber content (5% and 7.5%) resulted in:

- Reduced workability
- Difficulty in compaction
- Fiber balling
- Increased voids

These effects negatively influenced strength and durability.

4.3 Failure Pattern

Control bricks exhibited brittle failure with sudden cracking, whereas fiber-reinforced bricks showed gradual failure and controlled crack propagation. The presence of polypropylene fibers enhanced toughness and post-crack behavior.

5. CONCLUSIONS

This experimental investigation demonstrates that polypropylene fiber significantly influences the performance of fly ash bricks. The major conclusions are:

1. Fly ash bricks can be effectively manufactured using industrial waste materials, contributing to sustainable and eco-friendly construction practices.
2. The incorporation of polypropylene fiber significantly influences the performance of fly ash bricks, particularly in terms of compressive strength and water absorption characteristics.
3. An optimum polypropylene fiber content of **2.5% by weight** was identified, at which the maximum improvement in performance was observed.
4. The compressive strength of fly ash bricks increased from **5.86 N/mm² to 6.28 N/mm² at 14 days** and from **6.70 N/mm² to 8.80 N/mm² at 28 days** with the addition of 2.5% polypropylene fiber.
5. The strength gain with curing age was more pronounced for fiber-reinforced bricks, indicating improved fiber–matrix interaction and effective crack control during hydration and pozzolanic reactions.
6. Water absorption of fly ash bricks was reduced to **6.20% at 14 days** and **6.00% at 28 days** for bricks containing 2.5% polypropylene fiber, demonstrating improved durability and reduced porosity.
7. Higher polypropylene fiber contents (5% and 7.5%) resulted in reduced compressive strength and increased water absorption due to poor workability, fiber agglomeration, and increased void content.
8. Failure pattern observations revealed that fiber-reinforced fly ash bricks exhibited controlled cracking and gradual failure compared to the brittle failure of conventional fly ash bricks.
9. The experimental results satisfy the standard requirements for masonry units, indicating that polypropylene fiber-reinforced fly ash bricks are suitable for structural and non-structural applications.
10. Overall, polypropylene fiber-reinforced fly ash bricks with optimum fiber content provide a viable, durable, and sustainable alternative to conventional clay bricks.

Future Scope

Further studies may focus on long-term durability, thermal and acoustic properties, microstructural analysis, and field-scale performance of fiber-reinforced fly ash bricks. Life-cycle assessment and codal recommendations can also be developed for large-scale adoption.

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